A HIGHLY LINEAR MESFET

S.L.G. Chu, J. Huang, W. Struble
G. Jackson, N. Pan, M.J. Schindler, Y. Tajima

Raytheon Company
Research Division
131 Spring Street, Lexington, MA 02173

ABSTRACT

A highly linear MESFET has been developed. This device incorporates a spike profile in its active channel, and was designed specifically for linearity.[1] A third-order intercept (IP3) and a 1 dB compression power of 43 dBm and 19 dBm, respectively, have been measured on a 400 μm device at 10 GHz. The difference between these two numbers, 24 dB, is the largest yet reported for a MESFET. This device also dissipates only 400 mw of dc power, yielding a linearity Figure-of-Merit (FOM) ($IP3/P_{dc}$) of 50.

INTRODUCTION

Many advanced electronic systems for space communication and electronic warfare require devices and circuits which have low noise, low third-order distortion, and low dc power consumption. A FOM which has been adopted for such applications is the ratio of IP3 to the dc power. Although MESFETs and HEMTs have been shown to have attractive low noise properties, they have not been considered suitable devices for applications requiring high linearity due to their typically low FOM (Table 1). The MESFET described here has a FOM of 50, which is the highest that has been reported for a GaAs FET. The third-order performance of such a device has been modeled. The agreement between the measured data and simulation at low drive levels is very good.

TABLE 1

Comparison of Measured IP3 For Different Types of Devices

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Device Type	Maker	Gain (dB)	$F_{min.}$/A.G. (dB/dB)	1 dB Comp P_{out} (dBm)	IP3 (dBm)	Δ (dB)	$\frac{IP3}{P_{DC}}$
Power MESFET	Raytheon	10.4	2.8/10.0 (E)	18.0	32.0	14.0	3.7
Single Pulse-doped PSHEMT	Raytheon	8 0	1.5/13.0	12 5	23.0	10.5	1.6
Double Pulse-doped PSHEMT	Raytheon	9.0	1.0/11.3	16 0	33.5	17.5	5 8
Spiked MESFET	**Raytheon**	**11.0**	**2.6/13.0**	**19.0**	**43.0**	**24.0**	**50.0**
HBT	TRW	7.0	N/A	13.9	35.0	21.1	44.0

DEVICE DESIGN

For MESFET amplifiers under small signal operation, such as those used for low noise applications, distortion is caused mainly by small nonlinearities in the transistor parameters such as g_m, c_{gs} and g_{ds}. If the operation is small signal, one can apply the Taylor series expansion to the drain current and the gate current around the bias point to determine these nonlinearities. The terms which contribute to the third-order distortion are:

$$\partial^2 g_m/\partial V_{gs}^2,\ \partial^2 g_m/\partial V_{ds}^2,\ \partial^2 g_{ds}/\partial V_{gs}^2,$$

$$\partial^2 g_{ds}/\partial V_{ds}^2,$$

$$\partial^2 C_{gs}/\partial V_{gs}^2, \ldots\ldots\ldots + \text{ cross terms}$$

A device design which eliminates these terms will provide device operation free of third-order distortion. A spike-doped device having a very large spike in the active region will provide such performance by ensuring that the depletion width changes little with gate voltage swing, therefore maintaining very linear g_m and C_{gs}.[1] Figure 1 shows the doping structure of the spike-doped MESFET. This structure was grown by MOCVD and the device has an 0.5 μm gate length. The Si spike doping was accomplished by interrupting the growth and flowing silane under an arsenic overpressure. The growth temperature was 650°C and the silane flow was 15 sccm with

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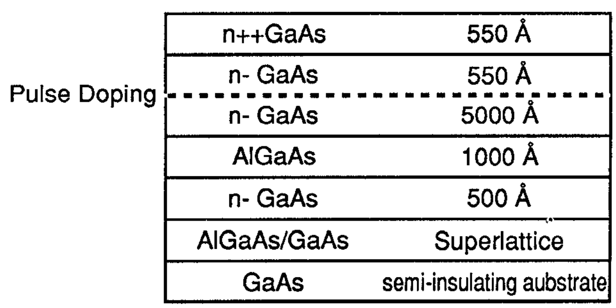

Figure 1. Device Structure of Spike-Doped MESFET.

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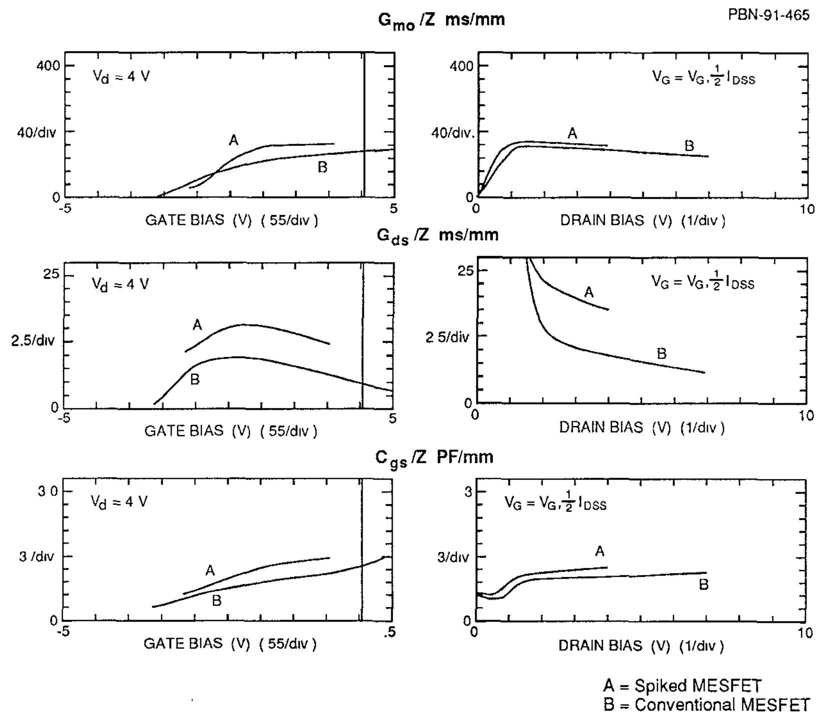

Figure 2. Comparison of G_m, G_{ds} and C_{gs} vs. Gate Bias and Drain Bias between a Spike-Doped MESFET and a Conventional MESFET.

an exposure time of 5 minutes. The abruptness of the spike is on the order of 100 Å and the verification of a two-dimensional electron gas has been confirmed by Shubnikov de Haas measurement.[2]

MEASUREMENT

Figure 2 shows a comparison of the g_m, C_{gs}, and g_{ds} vs. gate bias and vs. drain bias [3] for a conventional uniformly doped MESFET and a spike-doped MESFET. Gate bias scan was measured at V_d = 4V and drain bias scan was measured at 1/2 I_{dss}. The g_m and C_{gs} of the spike-doped MESFET is more linear than that of the regular MESFET as expected, and since the g_{ds} vs. V_g curve for the two devices have about the same slope at the bias point, this non-linearity contributes equally in each device, but is less important than g_m or C_{gs} contributions.

The third-order intermodulation of the device was measured. The two-tone test frequencies were 10.0 and 10.06 GHz. Figure 3 shows the measured third-order products and the fundamental output power as a function of input power for a 400 μm spiked-doped MESFET biased at V_d = 4V and 1/2 I_{dss} (97 mA). The small signal gain was 11 dB with a third-order intercept of 43 dBm. The difference between IP3 and 1 dB compression power is 24 dB. This is the highest that has ever been reported for a FET-like device. Figure 4 shows the results of a 75 μm device biased at V_d = 4V and I_d = 18 mA. At the low drive level, third-order products take a 3:1 slope, as

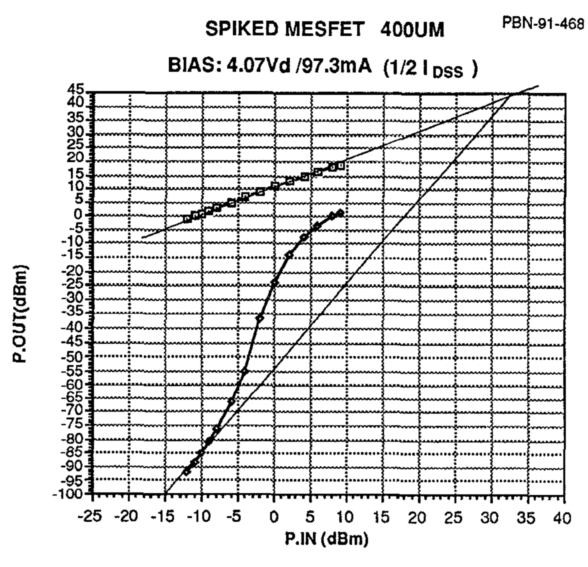

Figure 3. Measured Third-Order Products and Fundamental Power of a Spiked MESFET.

expected. Table 1 summarizes the measured linearity FOMs for different types of devices. The spike-doped MESFET and a recently reported HBT [4] designed for high linearity give the highest FOMs (IP3 mw/P_{dc} mw).

MODELING

In order to determine the optimum impedance for best IP3 performance and to design to that impedance, accurate modeling is essential. The IP3 performance of a 400 μm device has been measured and simulated in both a 50 ohm test jig and a tuned test jig. The device's pulsed I-V [5] curves have been measured from the quiescent bias point, and the small signal model parameters have been measured as a function of bias. Materka large signal model coefficients [6] have been extracted from the pulsed I-V data and small signal models. Figures 5 and 6 show measured and modeled pulsed I-V and C_{gs} data as a function of bias. The agreement is excellent. Figure 7 shows the measured and LIBRA® simulated fundamental and third-order performance of the tuned jig case. Figure 8 shows that of the 50 ohm case. Good agreement has been obtained at the low drive level for both tuning cases.

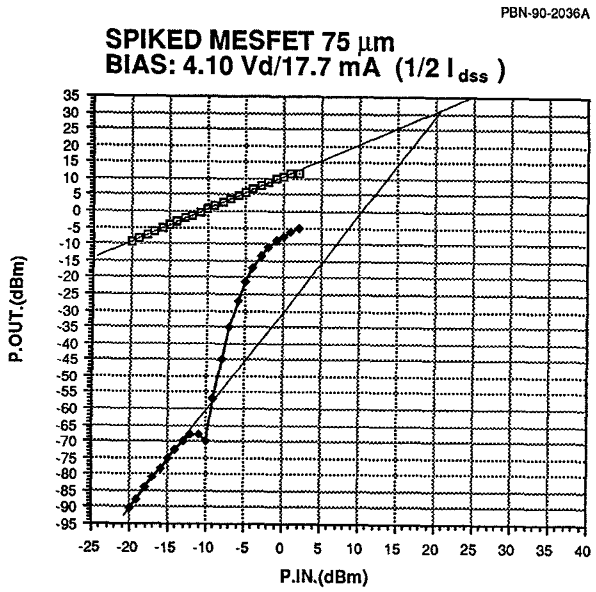

Figure 4. IP3 Results of a 75 μm Device.

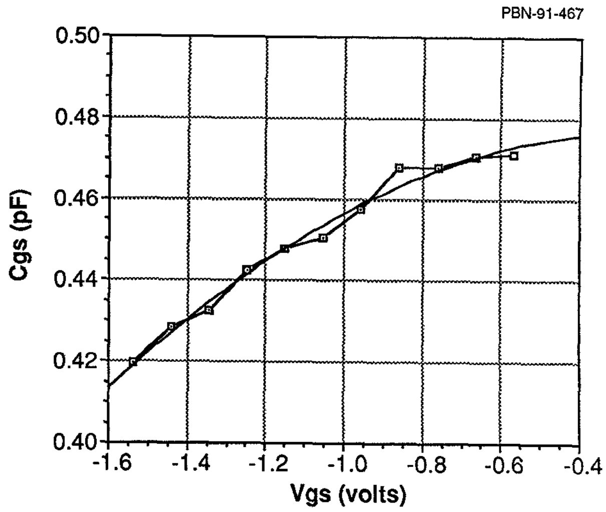

Figure 6. Modeled and Measured C_{gs}.

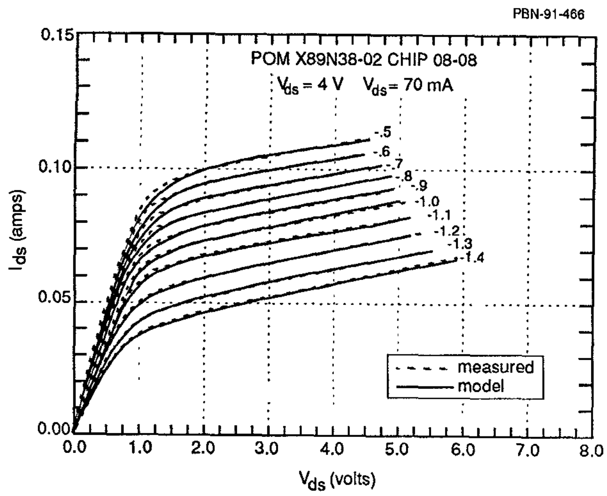

Figure 5. Modeled and Measured Pulsed I-V Data.

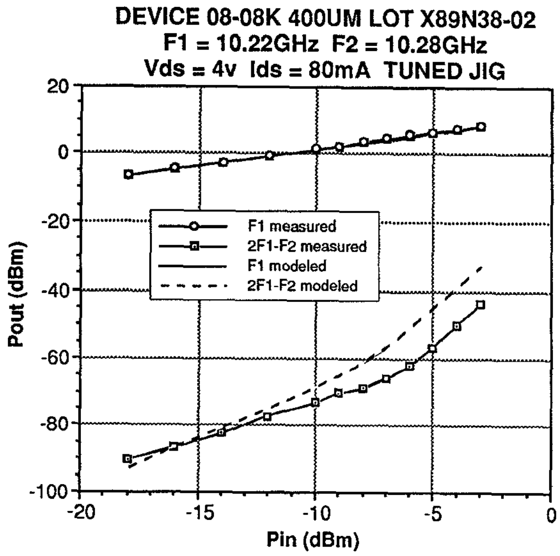

Figure 7. Measured and Simulated Results of a 400 μm Device in a Tuned Jig.

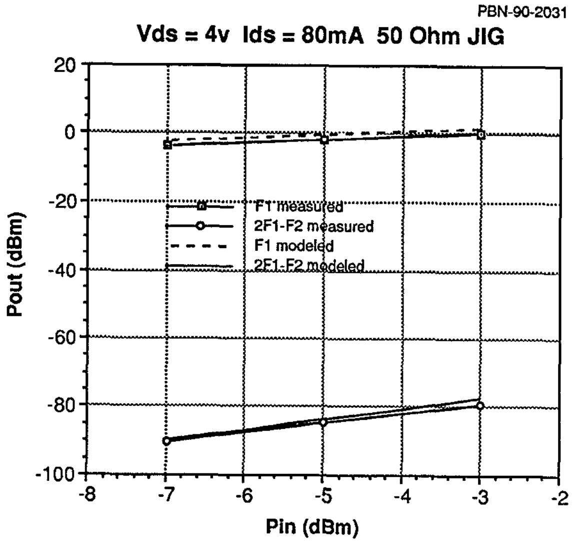

Figure 8. Measured and Simulated IP3 Results in a 50 Ohm Jig.

CONCLUSION

A highly linear MESFET has been demonstrated at 10 GHz with a high linearity FOM. With the success in modeling its IP3 performance, this work has paved the way to future development of a family of highly linear systems.

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